Effect of BMI on Lifetime Risk for Diabetes in the U.S.

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OBJECTIVE — At birth, the lifetime risk of developing diabetes is one in three, but lifetime risks across BMI categories are unknown. We estimated BMI-specific lifetime diabetes risk in the U.S. for age-, sex-, and ethnicity-specific subgroups.

RESEARCH DESIGN AND METHODS — National Health Interview Survey data (n = 780,694, 1997–2004) were used to estimate age-, race-, sex-, and BMI-specific prevalence and incidence of diabetes in 2004. U.S. Census Bureau age-, race-, and sex-specific population and mortality rate estimates for 2004 were combined with two previous studies of mortality to estimate diabetes- and BMI-specific mortality rates. These estimates were used in a Markov model to project lifetime risk of diagnosed diabetes by baseline age, race, sex, and BMI.

RESULTS — Lifetime diabetes risk at 18 years of age increased from 7.6 to 70.3% between underweight and very obese men and from 12.2 to 74.4% for women. The lifetime risk difference was lower at older ages. At 65 years of age, compared with normal-weight male subjects, lifetime risk differences (percent) increased from 3.7 to 23.9 percentage points between overweight and very obese men and from 8.7 to 26.7 percentage points for women. The impact of BMI on diabetes duration also decreased with age.

CONCLUSIONS — Overweight and especially obesity, particularly at younger ages, substantially increases lifetime risk of diagnosed diabetes, while their impact on diabetes risk, life expectancy, and diabetes duration diminishes with age.

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The prevalence of diagnosed diabetes among U.S. adults has risen twofold in the past 40 years and 75% during the past 25 years (1,2). The lifetime risk of diabetes in the U.S. in 2000 was 33% for male subjects and 39% for female subjects and was even higher among U.S. minority groups (3). BMI is a powerful and modifiable risk factor for diabetes (4,5). However, the impact of BMI on the lifetime risk of diabetes has not been evaluated, and no data are available on the comparative lifetime risks of diabetes across categories of BMI. Because lifetime risk estimates are easily understood measures of the impact of disease in individuals (6,7), they have been used in public education campaigns for disease prevention (10–14). Lifetime risk estimates for diabetes according to BMI would be valuable for *1*) communicating an individual's risk of diabetes given his/her BMI and 2) identifying groups of individuals who would benefit most from primary prevention.

In this study, we estimate the lifetime risk of diabetes (risk from age 18 years until death or age 85 years) by baseline age, race, sex, and BMI for the U.S. population and present the results in a form suitable for communication with individuals at risk and with policy makers.

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Abbreviations: NHIS, National Health Interview Survey.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

RESEARCH DESIGN AND METHODS

— We calculated prevalence and incidence rates for 2004 from the nationally representative U.S. National Health Interview Survey (NHIS) data (8–11). Multiyear data (1997–2004) were modeled to improve precision of estimates for 2004. The NHIS is an ongoing, continuous, nationwide, cross-sectional survey of the U.S. noninstitutionalized population. The NHIS uses a multistage probability sampling strategy to select households and individuals each year. Between 1997 and 2004, 301,840 households and 780,694 individuals participated, and in 2004 alone, 36,579 households and 94,460 individuals participated. The overall response rate varies annually but is ~90%.

Prevalence was assessed from the answer to the question, "Have you ever been told by a doctor or health professional (other than during pregnancy, if female) that you have diabetes or sugar diabetes?" Incidence was assessed from age at the time of survey and the answer to the question, "How old were you when a doctor first told you that you had diabetes or sugar diabetes?" We calculated the number of years each person had been diagnosed with diabetes by subtracting the age at which they were diagnosed from their current age. Adults who had a value of 0 were identified as having been diagnosed with diabetes within the last year; one-half of the adults who had a value of 1 were classified as having been diagnosed with diabetes within the last year. Self-reported weight and height were used to calculate BMI.

There were 15,843 prevalent cases of diagnosed diabetes among the 242,957 respondents, and 1,514 incident cases among the 228,628 nondiabetic respondents, aged 18–84 years, in the NHIS for 1997–2004. We used Bayesian hierarchical logistic regression (12) with random intercepts by calendar year to estimate diabetes prevalence and incidence as a function of age (18–84 years in 1-year intervals), race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, or other), sex, and BMI (underweight, <18.5 kg/m^2; normal weight, 18.5 to <25 kg/m^2; overweight, 25 to <30 kg/m^2; obese, 30 to <35 kg/m^2; and very

Table 1—*Remaining lifetime risk of developing diabetes by baseline BMI and age*

Baseline age (years)	BMI group (kg/m^2)	Remaining lifetime risk							
		Non-Hispanic							
		White		Black		Hispanic		Total	
		Male	Female	Male	Female	Male	Female	Male	Female
18									
	<18.5	6.2	9.8	9.0	14.9	9.7	15.5	7.6 (0.2–25.9)	12.2 (4.0–24.4)
	18.5 to <25	16.9	14.5	21.4	18.4	25.0	21.5	19.8 (16.1–23.8)	17.1 (14.2–20.4)
	25 to <30	25.5	30.7	33.1	39.3	36.9	43.4	29.7 (25.9–33.7)	35.4 (31.3–20.4)
	30 to <35	51.8	48.8	61.3	60.1	68.1	66.0	57.0 (51.4–62.6)	54.6 (49.2–60.3)
	35+	66.1	69.3	72.9	79.8	81.1	86.0	70.3 (63.9–76.5)	74.4 (69.1–79.3)
45									
	<18.5	6.0	9.1	9.2	14.1	9.3	14.0	6.9 (0.1–23.8)	10.6 (3.1–22.2)
	18.5 to <25	15.9	13.2	20.7	16.7	23.3	18.9	17.7 (14.2–21.5)	14.7 (12.1–17.7)
	25 to <30	23.7	27.5	31.7	35.6	33.8	38.0	26.2 (22.7–30.0)	30.4 (26.5–34.7)
	30 to <35	47.5	42.2	59.2	53.4	62.9	56.4	50.9 (45.1–56.9)	45.8 (40.3–51.7)
	35+	59.4	58.4	71.0	71.2	75.6	74.5	62.7 (55.2–69.8)	62.2 (55.9–68.4)
65									
	<18.5	2.1	3.5	2.5	4.2	3.0	4.9	2.2 (0.0–8.7)	3.7 (0.7–9.4)
	18.5 to <25	10.2	9.0	10.3	8.7	14.0	11.9	10.8 (8.2–13.7)	9.3 (7.4–11.7)
	25 to <30	13.8	17.3	14.4	17.5	18.6	22.5	14.5 (11.7–17.6)	18.0 (14.9–21.6)
	30 to <35	28.3	26.3	29.8	26.9	37.2	33.8	29.6 (23.8–36.1)	27.3 (22.0–33.1)
	35+	33.2	34.9	35.2	35.7	43.6	44.3	34.7 (25.8–44.5)	36.0 (27.8–45.0)

Data are percent or percent (95% Bayesian CI).

obese, >35 kg/m^2). To derive 2004 age-, race/ethnicity-, sex-, BMI category–, and diabetes-specific mortality rates, we used the following additional sources: *1*) U.S. Census Bureau 2004 population and mortality rates by age, race/ethnicity, and sex (13); *2*) NHIS estimates of BMI prevalence by age-group, race/ethnicity, and sex; *3*) age-group– and sex-specific relative risk estimates of death attributable to diabetes (14); and *4*) age-group– and BMI-specific relative risk estimates of death (15).

Markov chain model

Markov chain models simulate the progression of individuals through mutually exclusive disease states. Transitions between states take place at discrete intervals, and the number of individuals who move from one state to another during each cycle is determined by transition probabilities (detailed in "A Markov Chain Model for Lifetime of Risk by BMI" found in an online appendix at http://dx.doi.org/10.2337/dc06-2544). For each race/ethnicity-sex-BMI combination, we estimated three age-specific 1-year transition probabilities for nondiabetic individuals up through age 84 years: *1*) the probability of remaining nondiabetic, *2*) the probability of becoming diabetic, and *3*) the probability of death without diabetes. We estimated two probabilities for individuals who have developed diabetes: *1*) the probability of remaining diabetic (for this analysis we assumed that once diagnosed, diabetes was not reversible) and *2*) the probability of dying with diabetes.

Using these probabilities in a Markov chain model (16), we estimated the following for each race/ethnicity, sex, and BMI category: *1*) the remaining lifetime risk for diabetes among indviduals who are not diabetic at a specific "baseline" age, *2*) the average remaining lifetime, and *3*) the average duration of diabetes. The Markov chain model presented here can be considered an extension of the life table technique. It begins with age-specific transition rates for a given time period, and then it assumes that this schedule of rates is in operation for the lifetime of a hypothetical birth cohort. This cohort is "aged" year by year to produce remaining lifetime risks for diabetes at each age, assuming that the age-specific transition rates do not change. We estimated 40 sets of parameters and the associated Markov chains corresponding to the race/ethnicity-sex-BMI combinations. We calculated all race/ethnicity estimates (Table 1) by weighing the race/ethnicity-specific values by the proportions of nondiabetic individuals in the 2004 U.S. population.

RESULTS

Lifetime risk by BMI

Lifetime diabetes risk increases with baseline BMI in both sexes and at every baseline age (Fig. 1). At 18 years of age, for male subjects, the remaining lifetime diabetes risk ranged from 7.6% for those with BMI <18.5 kg/m^2 to 70.3% for those BMI >35 kg/m^2. For female subjects, the remaining lifetime risk ranged from 12.2 to 74.4% for baseline BMIs of <18.5 and >35 kg/m^2, respectively. The increase in remaining lifetime diabetes risk by BMI, however, is less steep at older baseline ages. At 65 years of age, the remaining lifetime risk ranged from 2.2 to 34.7% for male subjects with BMIs of <18.5 and >35 kg/m^2, respectively, and from 3.7 to 36.0% for female subjects with BMIs of <18.5 and >35 kg/m^2, respectively.

At 18 years of age, compared with normal weight, the absolute increase in lifetime risk for male subjects was 9.9, 37.2, and 50.5 percentage points for overweight, obese, and very obese, respectively; for female subjects, the absolute increase in lifetime risk was 18.3, 37.5, and 57.3 percentage points, respectively. By comparison, at 65 years of age, com-

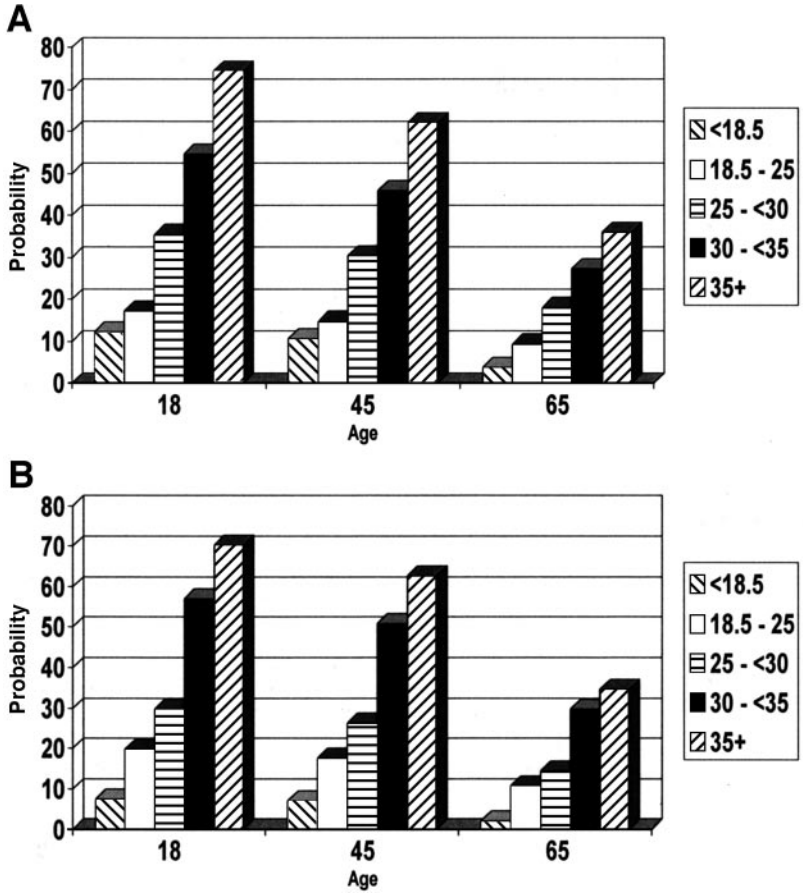

Figure 1— *Remaining average lifetime risk of diabetes by age and BMI among women* (A) *and men* (B).

pared with normal weight, lifetime risk increased for male subjects by only 3.7, 18.8, and 23.9 percentage points for overweight, obese, and very obese, respectively, and for female subjects by only 8.7, 18.0, and 26.7 percentage points. The remaining lifetime risk for diabetes was generally higher among minority groups in both sexes and at all ages and baseline BMI strata (Table 1).

Expected years with and without diabetes

The average number of years of life remaining with and without diabetes by sex, baseline age, and BMI are shown in Fig. 2. Women, on average, have both longer life expectancies and spend more years with diabetes. There is a U-shaped association between BMI and life expectancy in men and women at all baseline ages, with the lowest life expectancy among individuals with BMI <18.5 kg/m^2 and those with BMI ≥ 35 kg/m^2. For example, remaining life expectancy at 18 years of age is 53.5 and 47.9 years for male subjects with BMI <18 and ≥ 35 kg/m^2, respectively, and 57.9 and 53.5 years, respectively, for female subjects. The impact of BMI on life expectancy and years spent with diabetes decreases with age. Because of the earlier onset of disease, the number of expected years with diabetes is longer with increasing BMI at all baseline ages and in both sexes. The impact of BMI on expected years with diabetes, however, decreases with increasing age.

CONCLUSIONS — Taken as a whole, our data suggest that adult lifetime risk of diabetes is most strongly affected by BMI ≥ 30 kg/m^2 and that the impact of BMI, expressed in terms of absolute risk of diabetes, diminishes with increasing age at risk. Our data also underscore the strong impact of obesity on diabetes-associated morbidity and mortality, but the impact of BMI on expected years with diabetes and life expectancy also decreases with age.

Although the lifetime risk of diabetes is directly related to BMI in both sexes, the incremental increase in absolute risk among men is larger between overweight and obese individuals than between normal weight and overweight individuals. These results are consistent with the findings that individuals with BMI ≥ 30 kg/m^2 have a clear elevated risk of death (15,17). Furthermore, recent analyses of national diabetes trends also indicate that the substantial majority of the secular increase in diabetes has occurred in individuals with BMI ≥ 30 kg/m^2 (18).

These estimates of lifetime risk for diabetes must be carefully interpreted. The lifetime risk estimates are for an "average person" in the U.S. population in 2004. The level of diabetes risk factors, especially obesity, genetic background, diet, physical activity, and socioeconomic factors, may raise or lower the lifetime risks away from the average for an individual.

Our data on diagnosed diabetes and BMI were based on self-report. The accuracy of self-reporting for diabetes is reasonably high in population surveys; self-reported diabetes has high specificity and a positive predictive value but low sensitivity (19,20). When comparing self-reported to measured weight and height, heavier individuals tend to underreport their weight more than leaner individuals, and shorter individuals tend to overreport their height (21). The magnitude of reporting error depends on the mode of assessment, however. For example, when prevalence estimates for obesity were compared, it was found that bias in self-reported weight was larger in telephone interviews than in-person interviews (22). In the setting of rigorous in-person interviews, as in the NHIS, it has been shown that relationships with serum glucose and other physiologic measures are equally strong for self-reported and measured weight and height (23).

We assumed that diabetes incidence rates would be constant over the remaining lifetime of the cohort, even though obesity is rapidly increasing in the U.S. (24). The incidence of diabetes may also consequently increase in the future (25,26). An additional factor that may limit the accuracy of our projections is the projected increase in life expectancy, particularly for U.S. ethnic minority groups (27), which will also increase the average lifetime risk for diabetes in the total U.S. population. Our estimates, however, are based on age-, sex-, race/ethnicity-, and BMI-specific diabetes incidence and mortality rates. Another limitation is that we did not have BMI-specific data on life expectancy for individuals with diabetes, and we had to use the relative risks of BMI

Figure 2—*Average number of years of life remaining with (■) and without (□) diabetes, according to baseline age and BMI among women* (A) *and men* (B).

on mortality for the general population in our estimations. Finally, we have computed remaining lifetime risks based on the BMI at one point in time. BMI, however, generally increases with age until the fifth and sixth decades of life and decreases thereafter (28). Although it is difficult to predict the magnitude and direction of bias attributable to use of a single BMI value, we may have underestimated risk attributable to BMI in our study. In younger adults, a single BMI value may lead to an underestimation of their risk of future diabetes because they will likely continue to gain weight for several decades. For older adults, a single BMI value may also lead to an underestimation of their remaining lifetime risk because it will not reflect the preceding decades of exposure to BMI levels that were likely elevated before experiencing age-related weight loss.

The data used for our estimates did not differentiate between type 1 and type 2 diabetes. However, type 2 diabetes accounts for up to 95% of cases (29). Among children, however, type 1 diabetes poses a greater risk, but we have defined lifetime risk as the risk of diabetes from age 18 years to death or age 85 years. Although the accuracy of our estimates depends on the accuracy of the relative risks for death from diabetes and of BMI that we used, we believe that the age-specific relative risk estimates used closely reflect those of individuals with diabetes in the U.S., and the age- and sex-specific estimates of relative risk that we used are consistent with recent estimates from a National Health and Nutrition Examination Survey (NHANES II) mortality study and with those from previous studies (30,31). If the true age-specific relative risks of death from diabetes are higher than the values we used, then the duration with diabetes will be less; however, the precise impact on lifetime risk of diabetes is not clear.

Unlike estimates of lifetime risks reported for other diseases and conditions—based on local or regional epidemiological cohort studies of disease incidence—our estimates are based on nationally representative data. Cohort studies are subject to several biases, including volunteer bias for healthy participants, and temporal trends within a cohort may also confound the estimation of lifetime risks. Our method of estimation of lifetime risk allows for more accurate inference to the general population than methods based on the experience of subjects followed in cohort studies.

Major clinical trials have shown that diabetes can be delayed or prevented among high-risk individuals (5). Our findings on the lifetime risk by BMI point to individuals with BMI ≥30 kg/m^2 as an important subgroup for targeted diabetes prevention efforts. This is particularly true among individuals ≥65 years of age, who are at increased risk of diabetes primarily because of age. Our analyses also confirm the large marginal increase in expected years with diabetes and in life-years lost from diabetes among individuals with BMI ≥30 kg/m^2 and the rather smaller impact among individuals with BMI 25–30 kg/m^2, compared with normal-weight individuals. Although obesity appears to have a much more pronounced impact on risk of diagnosed diabetes than overweight, there is concern about young individuals who begin adulthood in the overweight category. This is because young adults who are already overweight are substantially more likely to become obese earlier in adulthood than their normal-weight peers.

Individuals with BMI ≥30 kg/m^2 are at substantially heightened lifetime risk of diabetes, excess years with diabetes, and excess life-years lost to diabetes. If this heightened risk can be communicated in a way individuals can readily understand, they may become motivated. Estimates of lifetime risks may help this process.

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